CLAIMS

What is claimed is:

1. A micro-mirror device, comprising:

a substrate;

at least one address electrode positioned over the substrate and configured to provide an electrostatic force;

at least one support member positioned over the substrate and extending upward above the substrate;

a mirror disposed over the at least one address electrode and coupled to the at least one support member, the mirror configured to deflect toward the substrate in response to the at least one address electrode applying the electrostatic force to a portion of the mirror; and

a spring member spaced apart between the substrate and the mirror and coupled to the at least one support member, the spring member being operable to deflect separately from the mirror and toward the substrate.

2. The micro-mirror device of claim 1, wherein the spring member is operable to assist in forcing the mirror upward when the electrostatic force is released.

3. The micro-mirror device of claim 1, wherein the spring member is operable to deflect independently with respect to the mirror and in response to the electrostatic force.

4. The micro-mirror device of claim 1, wherein the spring member is configured to increasingly store energy from a neutral position to a maximum deflected position.

5. The micro-mirror device of claim 1, wherein the mirror comprises first and second side portions with a central axis defined therebetween, the mirror being operable to pivot about the central axis between a first and second position with the spring member configured to assist in pivoting the mirror to at least one of the first and second positions.

6. The micro-mirror device of claim 5, wherein the at least one electrode comprises first and second electrodes disposed below the first and second side portions of the mirror and configured to deflect at least one of the mirror and the spring member to the first and second

positions by alternating the electrostatic force applied through the respective first and second electrodes.

7. The micro-mirror device of claim 5, wherein the spring member is configured to store energy between a neutral position and a maximum deflected position and releases the stored energy to assist in alternately forcing the mirror upward to at least one of the first and second positions.

8. The micro-mirror device of claim 7, wherein the spring member is configured to deflect discretely to contact the substrate in response to the electrostatic force, the spring member being configured to release the stored energy, in response to the electrostatic force being released, once one of the first and second side portions of the mirror contacts the spring member to assist in forcing the one of the first and second side portions of the mirror upward to one of the first and second positions.

9. The micro-mirror device of claim 5, wherein the spring member comprises opposite first and second spring portions extending outward below respective first and second side portions of the mirror.

10. The micro-mirror device of claim 1, wherein the spring member is operable to assist in controlling a frequency of the mirror deflecting between a first position and a second position.

11. The micro-mirror device of claim 1, further comprising a dielectric liquid configured to immerse at least the spring member and the mirror.

12. The micro-mirror device of claim 11, further comprising a transparent plate positioned over the dielectric liquid and positioned substantially parallel with the substrate.

13. The micro-mirror device of claim 1, wherein the spring member comprises a conductive material configured to respond and deflect independently to the electrostatic force.

14. The micro-mirror device of claim 1, wherein the spring member comprises a piezoelectric element and is configured to deflect in response to the piezoelectric element.

15. The micro-mirror device of claim 1, wherein the substrate comprises logic circuitry formed therein configured to control the at least one address electrode.

16. A display apparatus, comprising:

multiple micro-mirror devices formed in an array on a substrate, at least one of the micro-mirror devices including:

at least one address electrode positioned over the substrate and configured to provide an electrostatic force;

at least one support member positioned over the substrate and extending upward above the substrate;

a mirror disposed over the at least one address electrode and coupled to the at least one support member, the mirror configured to deflect toward the substrate in response to the at least one address electrode applying the electrostatic force to a portion of the mirror; and

a spring member spaced apart between the substrate and the mirror and coupled to the at least one support member, the spring member being operable to deflect separately from the mirror and toward the substrate.

17. The display apparatus of claim 16, further comprising a dielectric liquid configured to immerse the array of micro-mirror devices.

18. The display apparatus of claim 17, further comprising a transparent plate positioned over the dielectric liquid and positioned substantially parallel with the substrate with the micro-mirror devices positioned between the substrate and the transparent plate.

19. The display apparatus of claim 16, wherein the spring member is operable to assist in forcing the mirror upward when the electrostatic force is released.

20. The display apparatus of claim 16, wherein the spring member comprises a conductive material configured to respond and deflect independently to the electrostatic force.

21. The display apparatus of claim 16, wherein the spring member is operable to deflect independently with respect to the mirror and in response to the electrostatic force.

22. The display apparatus of claim 16, wherein the spring member is configured to increasingly store energy from a neutral position to a maximum deflected position.

23. The display apparatus of claim 16, wherein the spring member comprises a piezoelectric element and is configured to deflect in response to the piezoelectric element.

24. The display apparatus of claim 16, wherein the substrate comprises logic circuitry formed therein configured to control the at least one address electrode.

25. A method of increasing the switching frequency of a micro-mirror device, the method comprising:

applying a voltage to at least one address electrode formed on a substrate to provide an electrostatic force to a spring member and a mirror each spaced apart from each other and disposed above the at least one address electrode;

deflecting a first spring portion of the spring member and a first mirror portion of the mirror, separate from each other, toward the substrate in response to the electrostatic force of the at least one address electrode;

releasing the electrostatic force from the at least one address electrode; and

forcing the first mirror portion upward with the first spring portion in response to energy stored in the spring member.

26. The method of claim 25, wherein the deflecting comprises deflecting the first spring portion of the spring member to a first position in contact with the substrate.

27. The method of claim 26, wherein the deflecting comprises deflecting the first mirror portion of the mirror to contact an upper surface of the first spring portion subsequent to the first spring portion contacting the substrate.

28. The method of claim 25, wherein the applying comprises alternately applying the voltage between first and second address electrodes positioned on respective first and second sides of the substrate and disposed below the respective first spring portion and a second spring portion and the respective first mirror portion and a second mirror portion.

29. The method of claim 28, wherein the forcing comprises pivoting the first mirror portion upward so that the second mirror portion deflects downward toward a second position on the second side of the substrate.

30. The method of claim 28, wherein the forcing comprises immediately applying the voltage to the second address electrodes to simultaneously deflect the second spring portion of the spring member and the second mirror portion of the mirror, separate from each other, toward the second side of the substrate.

31. The method of claim 30, wherein the forcing comprises pivoting the first mirror portion and the second mirror portion about a central mirror axis between a respective first position and a second position with a controlled frequency in response to (i) the electrostatic force alternately applied to the first and second address electrodes, and (ii) energy stored in the first and second spring portions of the spring member alternately forcing the respective first and second mirror portions upward.

32. The method of claim 25, wherein the deflecting comprises increasingly storing energy in the spring member as the spring member deflects from a neutral position to a maximum deflected position.

33. The method of claim 25, wherein the deflecting comprises deflecting the spring member independent of the deflecting of the mirror.

34. The method of claim 25, wherein the deflecting comprises deflecting the spring member and the mirror while being immersed in dielectric liquid.

35. A micro-mirror device, comprising:

a substrate;

a mirror positioned over the substrate and operatively coupled thereto and configured to pivotably actuate toward the substrate between a first position and a second position; and

a spring member operatively coupled to the substrate and spaced apart between the substrate and the mirror, the spring member being operable to deflect separately from the mirror and toward the substrate.

36. The micro-mirror device of claim 35, wherein the spring member is configured to deflect in response to an electrostatic force provided by at least one address electrode formed in the substrate.

37. The micro-mirror device of claim 35, wherein the mirror is configured to pivot at least partially in response to an electrostatic force provided by at least one address electrode formed in the substrate.

38. The micro-mirror device of claim 35, wherein the spring member comprises a piezoelectric element and is configured to deflect in response to the piezoelectric element.

39. The micro-mirror device of claim 35, wherein the spring member is operable to assist in forcing the mirror upward to at least one of the first position and the second position.

40. The micro-mirror device of claim 35, wherein the spring member is configured to increasingly store energy from a neutral position to a maximum deflected position.

41. A micro-mirror device, comprising:

a substrate;

a mirror positioned over the substrate and operatively coupled thereto, the mirror operable to deflect to at least a first position and a second position;

spring means for assisting in forcing the mirror from at least one of the first position and the second position; and

deflecting means for deflecting the mirror and the spring means, separate from each other, toward the substrate.

42. The micro-mirror device of claim 41, wherein the deflecting means comprises an electrostatic force.

43. The micro-mirror device of claim 41, wherein the deflecting means comprises at least one of an electrostatic force and a piezoelectric element.